REDUCING AVIATION WEATHER-RELATED ACCIDENTS THROUGH HIGH-FIDELITY WEATHER INFORMATION DISTRIBUTION AND PRESENTATION

H. Paul Stough, Daniel B. Shafer, and Philip R. Schaffner
NASA Langley Research Center, Hampton, VA USA
and
Konstantinos S. Martzaklis
NASA Glenn Research Center, Cleveland, OH USA

Keywords: *Aviation, Weather, Cockpit Systems*

Abstract

In February 1997, the U.S. President announced a national goal to reduce the fatal accident rate for aviation by 80% within ten years. The National Aeronautics and Space Administration established the Aviation Safety Program to develop technologies needed to meet this aggressive goal. Because weather has been identified as a causal factor in approximately 30% of all aviation accidents, a project was established for the development of technologies that will provide accurate, timely and intuitive information to pilots, dispatchers, and air traffic controllers to enable the detection and avoidance of atmospheric hazards. This project addresses the weather information needs of general, corporate, regional, and transport aircraft operators. An overview and status of research and development efforts for high-fidelity weather information distribution and presentation is discussed with emphasis on weather information in the cockpit.

1 Introduction

The National Aeronautics and Space Administration (NASA) has a rich history of conducting research to address aviation-related safety and operating challenges. Although there has been significant research over the past twenty years related to weather hazards such as icing, turbulence, lightning and wind shear, weather is still identified as a causal factor in 33% of commercial air carrier accidents and in 27% of general aviation accidents. A continuing area of need is the collection, processing, distribution, and presentation of timely and accurate weather information to the flight deck, air traffic control, and aircraft operation centers for both strategic and tactical decision making.

With the present system, pilots can have difficulty obtaining weather information in a timely manner, assimilating that information into a clear mental picture, developing a good understanding of changing weather trends, and making rapid and accurate decisions concerning route, while simultaneously managing cockpit activity and controlling the airplane. A flight crew that lacks a complete awareness of the weather situation may encounter adverse weather or may have difficulty making alternate route decisions. Airline Operations Centers (AOC), dispatchers, Flight Service Stations (FSS), and air traffic controllers (ATC) would also benefit from more timely weather information that they could disseminate to the flight crew as well as could use to assist the crew in making decisions such as those associated with route changes.

In the early 1990's, a Cockpit Weather Information (CWIN) system was developed and evaluated by a NASA-industry team to examine the benefits of combining and presenting various types of weather information obtained through multiple data link sources to aid crews with effective flight management [1 and 2].

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2000**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Reducing Aviation Weather-Related AccidentsThrough High-Fidelity Weather Information Distribution And Presentation**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NASA Langley Research Center, Hampton, VA USA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

See also ADM002333. International Congress of Aeronautical Sciences (ICAS) (22nd) Held in Harrogate, United Kingdom on August 27-September 1, 2000. U.S. Government or Federal Purpose Rights License, The original document contains color images.

14. ABSTRACT

In February 1997, the U.S. President announced a national goal to reduce the fatal accident rate for aviation by 80% within ten years. The National Aeronautics and Space Administration established the Aviation Safety Program to develop technologies needed to meet this aggressive goal. Because weather has been identified as a causal factor in approximately 30% of all aviation accidents, a project was established for the development of technologies that will provide accurate, timely and intuitive information to pilots, dispatchers, and air traffic controllers to enable the detection and avoidance of atmospheric hazards. This project addresses the weather information needs of general, corporate, regional, and transport aircraft operators. An overview and status of research and development efforts for high-fidelity weather information distribution and presentation is discussed with emphasis on weather information in the cockpit.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**13**	

Piloted simulation studies and flight evaluations on a transport aircraft demonstrated the ability of cockpit graphical weather information to enhance efficiency, safety, and situation awareness. Building on this experience and utilizing advances in forecasting, data processing, transmission, and display technologies, NASA is working to accelerate the development and implementation of such aviation weather information systems.

2 Background

In February 1997, the U.S. President announced a national goal to reduce the fatal accident rate for aviation by 80% within ten years. A NASA-sponsored Aviation Safety Investment Strategy Team (ASIST) defined research needs and the relative priority of each based on technology readiness and potential impact on safety. The ASIST participants identified weather accident prevention as a key area to be addressed and prioritized research and development investment areas (Fig. 1). At the top of the list were data dissemination and crew/dispatch/air traffic control monitoring, presentation, and decision aids. Weather product generation and advanced aviation meteorology were also among the top priorities.

Priority	Investment Area
1	Data Dissemination
2	Crew/Dispatch/ATC Monitoring, Presentation, and Decision Aids
3	Icing Hazard Solutions
4	Training
5	Weather Product Generation
6	Advanced Aviation Meteorology
7	Turbulence Hazard Solutions
8	Advanced Technology Vision and Tactical Sensors/Systems
9	Near Term Tactical Sensors/System
10	Strategic Wake Vortex Information
11	Hazard Characterization
12	Runway Contamination

Figure 1. ASIST weather research priorities

In April 1997, the U.S. National Aviation Weather Program Council issued a strategic plan [3] aimed at providing improved information and tools needed to enable aviation personnel to make sound and safe decisions regarding weather hazards. This plan was followed by the definition of National Aviation Weather Initiatives [4]. Research identified for NASA includes multi-functional color cockpit displays of weather hazards; cockpit oriented weather products; flight information services and communications systems; quantification of hazards; and satellite-based, ground-based, and aircraft-mounted forward-looking technologies for hazard sensing.

NASA established the Aviation Safety Program (AvSP) to develop technology products needed to help the Federal Aviation Administration (FAA) and the aviation industry meet the President's safety challenge. NASA’s role is to pursue, jointly with industry, those difficult-to-achieve and high technical risk projects which industry cannot pursue alone because of a lack of facilities, technical expertise, and research capital. NASA will develop aircraft system and subsystem prototypes and evaluate them in an appropriate environment. NASA will work with, and rely on, industry and FAA partners to implement the technologies.

3 Weather-Related Accidents

Huettner [5] has traced the history of transport aircraft safety improvement. The U.S. accounts for about half of the world's air travel but has only accounted for 8 percent of fatalities on airlines around the world since 1990. Matthews [6] observes that most of our current large jet fleet will continue to be with us for a long time, and improvements to aviation safety will not come from radically new aircraft as much as from technological changes within the aviation infrastructure. Huettner sees the information technology revolution as offering the next opportunity for major reductions in accident rates. He also observes that aviation weather is the one major variable that is not within the

control of technology or aviation system planners. In his view, the optimal weather information system would tell us only what we need to know, allow us to go as close to hazardous weather as we could for maximum efficiency of flight, and yet not subject the aircraft or its passengers to conditions that would be hazardous or undesirable. The end objective would be real-time strategic and tactical weather information that could be used to separate aircraft from hazardous weather in the same way we separate aircraft from aircraft today.

An Aircraft Owners and Pilots Association Air Safety Foundation study [7] has indicated that 27% of general aviation (GA) accidents involve adverse weather conditions. Furthermore, 30% of these weather-related accidents resulted in fatalities; that is, one out of every twelve GA accidents was a fatal weather-related accident. Continued visual flight rules (VFR) operation into instrument meteorological conditions (IMC) was the deadliest of all types of weather-related accidents, as 82% resulted in fatalities. Poor pilot judgment was cited as a key factor in most GA weather-related accidents. Ritchie [8] notes that, "Deteriorating weather conditions are frequently the cause of changes in flight objectives. The pilot needs to know quickly where the weather is better and what to do to get there."

4 Aviation Weather Information Systems

At its simplest, an aviation weather information system (Fig. 2) consists of weather products, a means for distributing the products to the users, and a means for presenting the information to the users. Data-link weather information systems are intended to provide information for longer-term strategic planning and to augment onboard sensors such as weather radar and lightning detectors that are used as short-term decision aids. Within the AvSP, weather products and information presentation are being addressed by an Aviation Weather Information (AWIN) element and distribution is being addressed by a Weather Information Communications (WINCOMM) element.

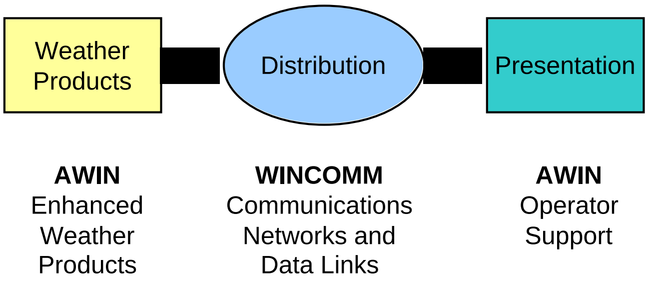

Figure 2. Weather information system elements

These system elements can be further subdivided as shown in Fig. 3. The Enhanced Weather Products area (indicated by light shaded or yellow boxes) is seen to encompass information from both onboard sensors and ground-based weather systems that provide strategic and tactical information to users. The Operator Support area (indicated by dark shaded or blue boxes) is seen to include the user-system interface, the method of information presentation, and decision aids. WINCOMM includes the data links and supporting networks connecting the elements. More than just weather information is needed by operators during the decision process. This includes aircraft capabilities, operator capabilities, and information on flight-path-relevant terrain, obstacles, air space, and traffic. Ultimately, the timeliness, accuracy and intuitiveness of weather information need to support decisions that result in safe and efficient actions.

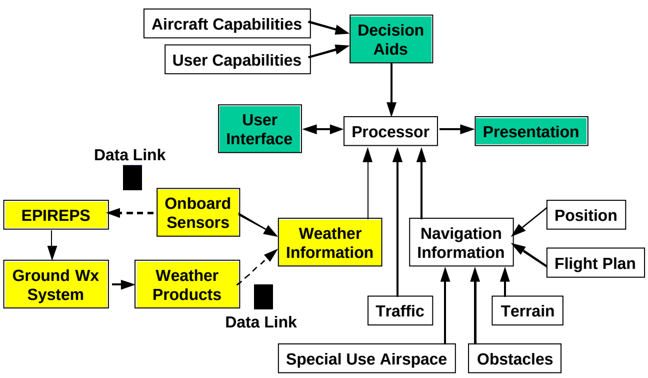

Figure 3. AWIN system components

AWIN must use an approach that addresses the overall airspace system. Solutions

must provide connectivity among the flight crew, ATC, dispatchers, and weather providers (Fig. 4). For GA, the dispatcher may be a fixed base operator (FBO) or corporate flight operations office, and the weather provider may be a FSS or a contracted weather provider. For regional and air carrier operations, the dispatch and weather provider functions may be combined in an AOC. NASA efforts are focusing on national weather information systems for GA and on worldwide systems for transport aircraft.

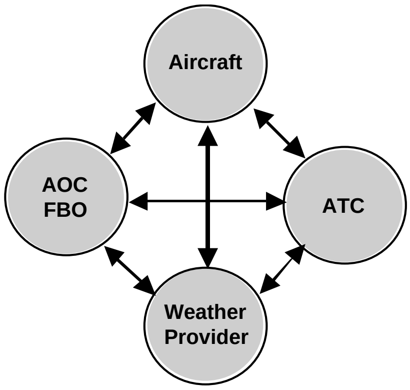

Figure 4. Weather information exchange

Initially, user-centered requirements for AWIN weather products, systems and components are being established. Existing and in-development weather information-related technologies and new concepts are being examined.

A market penetration study [9] has projected that cockpit weather systems will achieve maximum market penetration levels within the next 25 years and will achieve 50% of these levels within the next 8 to 11 years. Results indicated that cockpit weather systems are a viable product concept with strong business cases in the transport, commuter, and business markets. In the GA and rotorcraft market segments, the business cases were sensitive to variations in cost and savings estimates. However, improved safety alone was found to be sufficient motivation for the GA and rotorcraft segments to adopt the technology. The features deemed as necessary for the market success of cockpit weather information systems were identified for each market segment. The main needs for cockpit weather information systems can be addressed through developments for transport and GA airplanes. Business aircraft needs were shown to be very similar to those of transport aircraft. Commuter aircraft needs combined those of both transport and GA aircraft.

Georgia Tech Research Institute has performed a study for NASA to establish weather information needs by category of user and phase of flight in support of both strategic and tactical decisions. This study included weather phenomena and their impact on aviation, an analysis of weather information needs for each of twelve flight phases, and an assessment of existing weather products to support each flight phase. National Transportation Safety Board reports for weather-related accidents were examined to identify deficiencies in existing weather products. Requirements, including content, geographic and spatial coverage, and timely availability, were compared to weather information available from current sources. The study also defined aviation weather sensor capabilities and needs for hazard avoidance.

4.1 Enhanced Weather Products

The Enhanced Weather Products component has the objective of developing new and derivative weather products, complementing existing weather sources with in situ and remote sensing capability where needed, to provide necessary information at appropriate temporal and spatial resolution for both tactical and strategic decision making. NASA will be contributing to the development of objective standards for describing weather conditions, preferably based on measurements from sensing systems, and the means to integrate them into weather information products to facilitate sound decision making. Aircraft-mounted, forward-looking technologies for weather hazard detection and remote satellite-based and ground-based sensor technologies are being explored. Sensor systems currently in use or under development for the detection and avoidance of weather

hazards, including turbulence and icing, are being investigated. Current emphasis is on the development of enhanced weather radar and automated weather reporting from aircraft.

The FAA, through its Aviation Weather Research Program, is working to reduce weather-related accidents and incidents and to reduce the impact of weather on system capacity and efficiency. Research teams have been established to develop improvements in specific areas of weather sensing, modeling and forecasting. An Aviation Digital Data Service (ADDS) has been implemented on the internet to provide end users access to weather products and the results of the applied research. Users will be able to acquire route-specific graphics of key variables such as icing, turbulence, clouds, and thunderstorms. ADDS is envisioned as becoming a primary source of information for cockpit weather displays. NASA is coordinating with the FAA to utilize these enhanced weather products for AWIN systems and to provide guidance for structuring the presentation of the weather products, especially in the cockpit.

The Naval Research Lab is being sponsored by NASA, the FAA, and the U.S. Navy to improve the ability to forecast near-coastal ceiling and visibility conditions. The Navy's Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) is being used because it has a high horizontal resolution. After improvements have been implemented and tested, ceiling and visibility products will be sent to the National Weather Service (NWS) and FAA facilities in the Southern California region to evaluate their effectiveness. The knowledge gained and the techniques developed should be applicable to the next-generation, operational NWS mesoscale model which will likely have horizontal resolution and physics that are similar to those of the current COAMPS.

4.2 Weather Information Communications

The Weather Information Communications (WINCOMM) element will develop advanced communications and information technologies to enable the high quality and timely dissemination of aviation weather information to all relevant users on the aviation information network, addressing both airborne and ground-based users. Key considerations are national and worldwide connectivity and cross-platform operations (i.e., transports, cargo carriers, regional airlines, and general aviation). This element will also develop advanced communications architectures, supported by communications network system modeling, and will support appropriate standards definition to enable the efficient implementation of advanced weather products.

The National Aviation Weather Program Council has targeted development of data-link capabilities to disseminate weather observations within 5 minutes of availability, and analyses and forecasts within 15 minutes of availability, in order to facilitate hazardous weather avoidance. To support the early demonstration of AWIN prototype systems addressing both domestic and worldwide weather data dissemination, existing data links such as very high frequency (VHF), Aircraft Communications Addressing and Reporting System (ACARS), and satellite communication will be utilized. The capabilities of existing and enhanced communications systems are being assessed to determine if they can handle the needs of the new weather products. These derivative communications technologies will be deployed during the 2001-2002 timeframe. Next-generation communications system architectures will be investigated and the most promising of these will be demonstrated in the 2004 timeframe.

Lockheed Martin, in partnership with Aviation Concepts, conducted a study for NASA to determine the requirements for ground-to-air data communications needed to support present and future aviation weather products in the U.S. The study noted that a number of commercial providers already subscribe to government-provided weather data sources and provide flight planning services to the aviation community. It is expected that

future ground-to-air communications will be dominated by various forms of data link. In the near term, the current systems will be augmented with digital information via VHF Data Link (VDL). The study noted that advances in internet technology, small powerful handheld portable computers, and cell phone approval for aviation applications could cause many aviation weather products currently accessible by phone, fax or the internet to become "in-flight" weather products.

Communication system architectures that can provide for the collection and dissemination of aviation weather information and distribution of advanced weather products to the various aviation platform classes, with the potential for implementation by 2007, have been studied. The movement of aeronautical data communications to use the International Civil Aviation Organization (ICAO) standard Aeronautical Telecommunication Network (ATN) greatly simplifies the technical details of the communication system architecture for AWIN. With the ATN, messages are delivered regardless of the communication link used. The specific link need only provide the required communication performance for the application. The implementation of ATN, however, may be inadequate to provide a significant level of weather data dissemination by 2007. Also, ATN compliant equipment may prove too expensive for some user classes, such as low-end GA.

Development of low-cost Flight Information Services (FIS) systems, which provide advisory rather than safety-critical information, can take advantage of commercial communications distribution systems rather than protected-spectrum government-owned systems. Costs can be reduced further through use of open system standards. Standardization is needed, especially for data compression, so that graphical weather products can be displayed on avionics from more than one supplier. Hence, the communications system architecture being defined for AWIN at the 2007 timeframe will be a hybrid of ATN and non-ATN systems, ground-based and satellite-based weather information broadcast and two-way systems including addressable air-to-ground return links for the collection of weather information from airborne sensors.

4.3 Operator Support

Research in the Operator Support area will enhance weather situation awareness through the development of advanced weather presentations and decision-making aids (Fig. 5). Advanced weather presentations will provide information in an intuitive format that is temporally and spatially relevant to the users and their environment. Weather related decisions will be facilitated through the development of “intelligent agents” that assist operators in formulating appropriate, safe, and efficient actions in both a strategic and tactical environment.

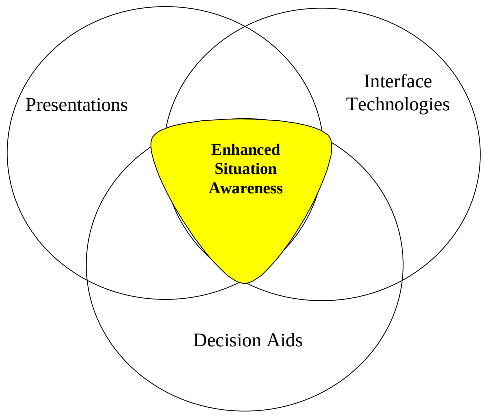

Figure 5. Operator Support components

Operator Support will develop adaptive, re-configurable presentations, advanced interface technologies, and decision-making aids coupled with a human-centered systems design approach. This methodology considers the capabilities and limitations of operators and helps to minimize the role of human error as a significant contributing factor in weather related aviation accidents.

To make the best use of emerging technologies, weather information system requirements must be defined in terms of the user's operational needs. Furthermore, the *perceived* operational needs of operators will be tempered with the operational information

required to execute a particular task safely and efficiently. To this end, NASA has teamed with the FAA Civil Aero-Medical Institute in determining the information requirements relative to specific operational tasks for the various phases of flight. Huettner [5] notes "we must know what decisions will be made and by whom. What information will be needed and who will have to communicate with whom to make decisions. Then we must know if decisions can be made unilaterally or whether negotiation is necessary. Successful negotiation depends on knowing the goals, intentions, and constraints (safety, economy, passenger convenience) of the other parties; the level and types of uncertainty induced by weather and actual versus planned action; the mutual trust of the parties involved; and the risk and workload tolerance of the parties."

The FAA Air Traffic Services organizations in a 1993 report defined their operational weather requirements [10]. Twenty-one high-level needs covering the collection, dissemination, and display of weather information were identified. The diverse U.S. pilot user groups provide an added challenge in the implementation of AWIN systems. There are over 600,000 active pilots in the United States and over 200,000 active civil aircraft (comprising approximately 192,000 GA aircraft and 8,000 air carrier aircraft). Furthermore, about 2,000 new aircraft are added each year. To contribute to an improvement in safety in the near future, retrofit issues and the ease of introducing new weather information technologies onto the flight deck are of primary concern. Installed and portable weather display technologies will be evaluated and displays will be formatted to meet the needs of the specific user groups.

Weather display capabilities are being combined with moving map navigation systems to enable route-specific weather presentations. Route planning and re-planning tools are being developed for avoiding adverse weather in the most advantageous manner. Ultimately, AWIN systems should provide users with ready access to the information needed to eliminate weather-knowledge-based precursors to accidents where the pilot and/or the aircraft may not be capable of safely penetrating adverse weather conditions.

Evaluation of AWIN systems and user interfaces are being performed to avoid increased workload and the creation of new causes of accidents. Operator Support will be considering such innovative technologies as wearable computing coupled with voice recognition as a means of achieving both the human error and flight deck integration challenges. The Team will leverage existing technology development efforts of industry and other federal agencies in providing these innovative solutions.

5 Cooperative Research

To accelerate development and implementation of aviation weather information systems, NASA has initiated cost-sharing projects with industry teams. Through these projects, the various disciplines involved in weather information systems - meteorology, communications, information management, human factors, and system integration - are being brought together in pre-competitive cooperative efforts.

5.1 Transport Systems

A team led by Honeywell International is developing a Weather Information Network (WINN) that provides graphical weather information to the cockpit of commercial airliners flying anywhere in the world. The network includes airborne displays, airborne and ground-based servers, and multiple providers of weather products and data link services. Since its inception in 1998, evaluations have been performed with systems installed in a Citation business jet and in a United Airlines B-777 full flight simulator (Fig. 6). System architecture, software, pilot interface, and communication links issues are being addressed. An open architecture has been adopted to accommodate any kind of data link technology. Both a satellite-based link and a terrestrial VHF/UHF telephone link have been

evaluated. Several different types of weather information can be overlaid or viewed individually. The current user interface employs dynamic soft buttons enabling activation of each of the functions with three button pushes or less. The latest version of the WINN system will be evaluated aboard a NASA B-757 transport research airplane beginning in August 2000. An in-service evaluation with a major airline using a laptop computer for the WINN system display is also planned for this year.

Figure 6. WINN display in B-777 simulator

A team led by Boeing has developed a complete weather information system with weather sources, terrestrial networks, and ground-to-air SATCOM communications. Text and graphical weather information is broadcast via a COMSAT Aero-H International Maritime Satellite channel for display on a laptop computer onboard the airplane. Coverage is provided along U.S., North Pacific, and West Pacific routes. Color weather graphics include composite radar mosaics (Fig. 7), lightning strike data, wind data, satellite images, and forecasts. In-service evaluations of this system have been conducted on a FedEx MD-11, a USAF C-135C, and a NC-21A transport flying stateside and overseas flights. Results of crew surveys will be used to guide improvements to weather information systems.

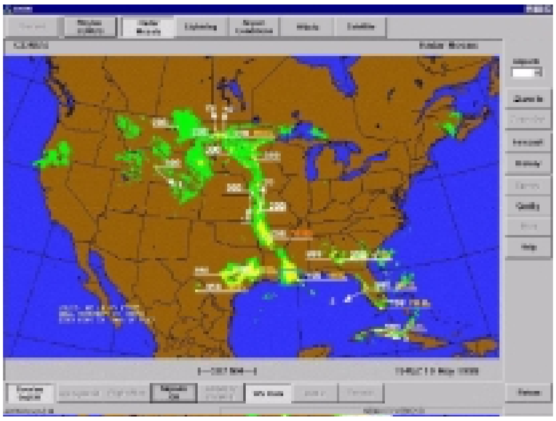

Figure 7. Boeing AWIN display

During the fall of 1999, a team led by Rockwell Collins conducted tests near Johannesburg, South Africa, that demonstrated the feasibility of delivering weather information to aircraft in flight through a low-cost antenna/receiver combination (Fig. 8) designed to receive data broadcast from Satellite-Digital Audio Radio Services (S-DARS) satellites. The WorldSpace AfriStar satellite was used to transmit the data. WorldSpace is the first satellite company to provide geostationary satellites with the capability to broadcast high-speed digital data for reception using simple patch antennas. Traditionally, a more expensive, beam-steered antenna solution has been required for airborne information transfer through satellites to ensure continuous beam pointing to the satellite. Cost of a beam-steered antenna alone has rendered such equipment inaccessible to a large segment of the aviation community. Weather graphics broadcast at 64kbits/second were received by a GA airplane equipped with a non-steered, flat patch antenna. Information was displayed on a laptop computer onboard the airplane. Continuous error-free data reception was achieved during normal aircraft maneuvers performed during takeoff, cruise and landing operations, including bank angles up to 45 degrees. Beginning in December 2000, NASA, Rockwell Collins, American Airlines, WorldSpace, Jeppesen, and the National Center for Atmospheric Research (NCAR) will evaluate a similar system for transport aircraft flying North Pacific routes from the U.S. to Tokyo and Hong Kong. Future

plans include evaluation of a dual frequency-band system that would allow signal reception from both U.S. and international satellite providers allowing operation in both domestic U.S. and international airspace.

Figure 8 (a). Rockwell Collins patch antenna

Figure 8 (b). S-DARS receiver

Rockwell is developing an enhanced on-board weather information system that will monitor both airborne and ground-based radar images and provide automatic storm analysis. The system, called Enhanced Weather Radar (EWxR), integrates information from the onboard X-Band weather radar with up-linked ground weather radar information and displays it to the crew properly oriented to aircraft heading (Fig. 9). Weather radar storm tracking algorithms that estimate the speed, direction, and cloud-top height of storm cells have been demonstrated. A "weather agent" is being developed with the ability to autonomously control an on-board weather radar and analyze weather radar images for hazardous features. Control of the radar by the weather agent will occur between normal radar scans and will not interfere with the pilot's control of the radar; however, the agent will be able to detect potential hazards and bring them to the attention of the pilot when necessary. Another expert system, based on knowledge acquired from weather experts and pilots, will enhance the displayed radar information by characterizing storms in terms relevant to pilots. A prototype system that combines in situ and up-linked weather radar images will be evaluated on the NASA B-757 beginning in August 2000.

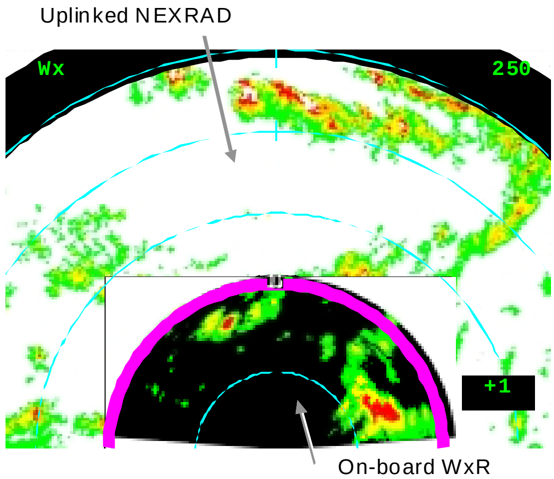

Figure 9. Rockwell EWxR display

The Honeywell Technology Center is developing a decision aid that enables dispatchers to optimize the route of flight of an airliner while avoiding adverse weather. Weather data and perception of weather hazards are being integrated into four-dimensional route optimization software that factors in the required time of arrival. User-centered interfaces to this optimization algorithm for pilots and dispatchers are being developed (Fig. 10). Evaluations by dispatchers and pilots have demonstrated a high level of performance and have identified functions and features required for a dispatcher's weather information system. The decision tool is being expanded to include more weather information relevant to dispatchers (i.e., terminal weather information) and to improve the graphical user interface based on initial evaluations. The resulting decision tool will be integrated into an existing dispatcher station at an AOC for a field evaluation of the decision tool and comparison to baseline capabilities. Ultimately, this work will be integrated with airborne AWIN systems

to address issues of collaborative decision-making with weather information.

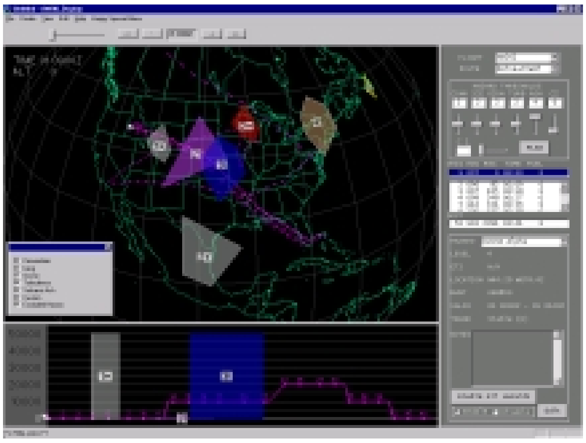

Figure 10. Honeywell route optimization interface

NCAR has developed automated algorithms that process satellite weather data to provide a timely summary of weather hazards to airline dispatchers, ATC, and the flight crews of en route aircraft in oceanic and remote areas (Fig. 11). The weather products, developed specifically for use by non-meteorologists and for dissemination to aircraft via existing data links, are generated in high-resolution, low-resolution, and character graphic formats to accommodate a complete spectrum of display and data link capabilities. From May through November 2000, United Airlines will conduct an operational evaluation of the delivery of convective weather products to B747-400 aircraft operating from the United States to Australia and New Zealand. Initially, weather products will be presented in the cockpit in the form of character graphics to achieve an early operating capability with current infrastructure and aircraft equipage. The ARINC ACARS will serve as the data link to en route aircraft.

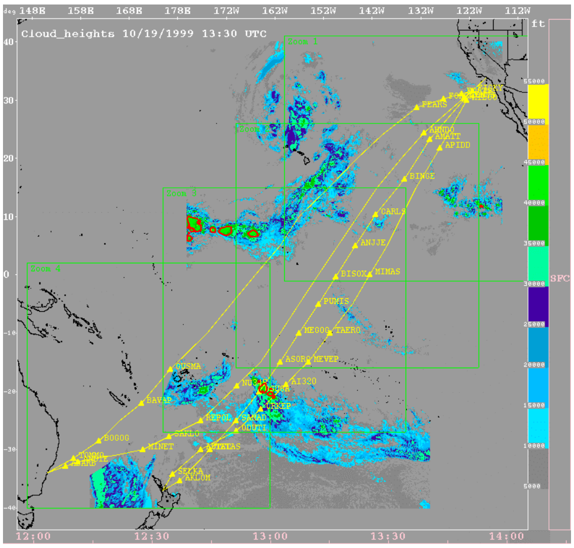

Figure 11. NCAR high resolution display of cloud heights over the South Pacific Ocean

5.2 General Aviation Systems

In May 1998, the FAA issued a policy statement advocating the rapid implementation of Flight Information Services Data Link (FISDL) and development of electronic pilot reporting of in situ weather conditions for GA. In July 1999, the FAA selected ARNAV and Honeywell International to implement FISDL as a data-linked weather-in-the-cockpit capability for GA aircraft beginning in early 2000. Basic text weather information will be broadcast free of charge to users. Graphical products such as weather radar mosaics may be provided on a fee basis. NASA is working with the FAA and industry to develop guidelines for the display of weather information which will ensure that the introduction of FISDL in the cockpit enables safer and more efficient flight operations without introducing hazardous and misleading information. Ongoing cooperative efforts with both ARNAV and Honeywell will expand on initial FISDL capabilities by developing and validating more advanced weather products and display capabilities.

Honeywell International leads a team in the development of an affordable, open architecture VDL mode 2-based weather and FIS broadcast, reception, and display system for GA. Various display devices, including

standalone portable units, are being explored. A virtual private network is being developed that will enable operational evaluation of experimental graphical route-oriented weather products for GA. Additionally, means will be explored to extend data link coverage to altitudes above the minimum 17,500 feet specified by the FAA for FISDL implementation.

ARNAV Systems leads a team that is developing a weather hazard information system for GA aircraft. The ARNAV team is utilizing FISDL infrastructure, air and ground data link equipment, and display avionics (Fig. 12) to develop and demonstrate a weather hazard index system that combines multiple weather hazards in a single weighted display format. The flight crew will be able to select the intensity of weather that will trigger various levels of alerting. This team will also provide in-flight evaluation of four advanced weather products currently being developed by NCAR. A total of 44 aircraft have been equipped with the ARNAV data link and display equipment for participation in flight tests.

Figure 12. ARNAV weather display

NASA and the FAA have teamed with Research Triangle Institute and Honeywell International to conduct experiments to assist in the implementation of FISDL for enhanced flight safety. Beginning in the spring of 2000, piloted simulations of flight scenarios impacted by adverse weather will be used to assess textual and graphical weather information presentation formats and the identification of any potential concerns that might result from the use of these products by GA pilots. Results will be reflected in operational guidelines published in the Aeronautical Information Manual.

One of the most sought-after products is the data-linked radar (DLR) mosaic, which will likely be used for convective weather avoidance in a variety of flight situations. DLR holds great promise for improving pilots' in-flight weather situation awareness. However, to date little is known about the accuracy and usability of DLR when compared with currently-available cockpit convective weather information and the effect that adding DLR to the cockpit will have on pilot decisions affecting flight safety and efficiency. A NASA flight experiment is underway to evaluate the responses of pilots to strategic and tactical convective weather situations, with and without access to DLR and outside visual weather cues.

Electronic pilot reporting (EPIREP) utilizes instrumented aircraft in flight as weather observing stations that report in situ conditions. Currently, the Meteorological Data Collection and Reporting System (MDCRS) collects automated position reports and weather data transmitted to the ground from participating airliners via ACARS and sends the information to the NWS for input to forecast models. Most of the observations are at high altitude, along defined airline routes, and lack humidity information. Moisture in the atmosphere, a key ingredient in weather phenomena, occurs predominantly at the lower altitudes frequented by GA aircraft. Thus, GA has the potential to make a significant contribution to improving weather products through the collection and dissemination of in-flight weather observations. This concept requires an extensive communications infrastructure among the various entities involved.

Input of more frequent weather observations can improve the forecasts from both current and future atmospheric models. These weather observations are needed on a regular basis if users are to be able to depend upon the availability of the resulting enhanced reporting and forecasting capabilities. Aircraft that are operated over defined routes on a

regular basis and that are capable of operating in IMC appear to be the best candidates for EPIREPS equipage. This points towards the regional commuter airlines and package carriers. Currently, NASA is working with the FAA Office of Airspace Management to identify the most appropriate aircraft to equip. Requirements for viable EPIREPS systems will reflect the data needs of the end users and the operational and cost constraints of the aircraft operators.

Two industry teams are currently working with NASA to develop EPIREPS capabilities for small aircraft. A team led by Honeywell International has undertaken the design, development, implementation, and evaluation of a practical system for automated electronic pilot reporting of weather conditions aloft from small and mid-sized aircraft in flight via VHF data link. The system combines sensors with a data-link transmitter on board the aircraft, ground receivers, a data collection network, and a central processing station. A compact airborne sensor package (Fig. 13) has been developed that provides airspeed, altitude, magnetic heading, vertical acceleration, temperature, humidity, and ice and ice depth detection at a single location on either the wing or fuselage. Work continues in developing an operational ground reception and processing network, conducting operational evaluations with equipped aircraft, and developing the capability for re-distribution of data to users such as Flight Service Stations and the National Weather Service.

Figure 13. EPIREPS sensor mounted under nose of light aircraft

ARNAV Systems is also developing EPIREPS capability for small airplanes and the ability to transmit the information to ground stations and to other aircraft. The ARNAV system includes sensors for air temperature and humidity, and also provides selector switches through which the pilot can indicate in flight icing conditions - no ice, clear ice, or rime ice. In-service evaluations are being conducted on four Federal Express Cessna Caravan aircraft (Fig. 14) flying in the Pacific northwest and mid-Atlantic parts of the U.S. These airplanes are certified for flight into known icing conditions and are typically flown by a single-pilot in both visual and instrument meteorological conditions. Five other airplanes have been equipped with sensors that allow temperature and humidity measurements to be relayed to the ground as EPIREPS.

Figure 14. Cessna Caravan aircraft

Rockwell is developing a flight planning tool that provides aviation weather awareness and reporting enhancements (AWARE). This work targets improvements for GA preflight weather briefing and en route situation awareness by integrating text-based and graphical weather information sources, and filtering information to display to the pilot only that which is route and/or time relevant (based on mission, equipment, flight rules, and pilot risk threshold). Rockwell has developed a web-based demonstration that provides ground-based weather radar imagery and depictions of surface weather phenomena such as temperature, dewpoint, pressure, winds, and visibility relative to the intended route of flight. A preliminary decision support model has been integrated into the demonstration that advises the pilot of probability of mission success based on pilot preferences, risk tolerance, and aircraft

equipage. Future enhancements will involve tailoring the preflight briefings to the type of flight plan (VFR or IFR), will incorporate additional types of weather information, and will integrate AWARE functionality with onboard systems.

6 Summary

Weather-related accidents comprise 33% of the commercial air carrier accidents and 27% of GA accidents. Using the inputs of industry and government, the research needed to reduce weather-related accidents has been identified and prioritized. NASA has established, within its Aviation Safety Program, elements to develop technologies that will provide accurate, timely and intuitive information to pilots, dispatchers, and air traffic controllers to enable the detection and avoidance of atmospheric hazards. Cognizant of the multitude of weather-related research and development activities underway, both in the US and in other countries, and the need to provide solutions for both national and international domains, NASA is partnering with other government agencies and industry to develop affordable and effective technologies to satisfy the needs of weather information systems and to realize the goal of reducing weather-related accidents.

7 References

[1] Scanlon, C. A Graphical Weather System Design for NASA Transport Systems Research Vehicle B-737. NASA TM 104205, 1992.

[2] Scanlon, C. Cockpit Graphical Weather Information Shown to Enhance Efficiency, Safety, and Situation Awareness. *Proceedings of the Flight Safety Foundation 39th annual Corporate Aviation Safety Seminar*, pp 83–94, 1994.

[3] National Aviation Weather Program Council Joint Action Group for Aviation Weather. National Aviation Weather Program Strategic Plan. Office of the Federal Coordinator for Meteorology, FCM-P32-1997, 1997.

[4] National Aviation Weather Program Council Joint Action Group for Aviation Weather. National Aviation Weather Initiatives. Office of the Federal Coordinator for Meteorology, FCM-P34-1999, 1999.

[5] Huettner, C. Toward a Safer 21st Century - Aviation Safety Research Baseline and Future Challenges. NP 1997-12-231-HQ, 1996.

[6] Matthews, S. Safety and Statistics: What the Numbers Tell Us about Aviation Safety at the End of the 20th Century. Flight Safety Foundation, Flight Safety Digest, 1997.

[7] AOPA Air Safety Foundation. Safety Review – General Aviation Weather Accidents – An Analysis & Preventive Strategies. 1996.

[8] Wiener, E, and Nagel, D. (editors). *Human Factors in Aviation*. Academic Press, p 578, 1998.

[9] Kauffmann, P and Pothanun, K. Estimating the Rate of Technology Adoption for Cockpit Weather Information Systems. SAE Paper 2000-01-1662, 2000.

[10] Air Traffic Weather Requirements Report prepared by the Air Traffic Weather Requirements Team, 1993.